PROPERTIES IMPACT FROM WASTEWATER TREATMENT SLUDGE UTILIZED INTO FIRED CLAY BRICKS

Aeslina Abdul Kadir[1], Nurul Salhana Abdul Salim[1], Mohd Mustafa Al Bakri Abdullah[2], Mohd Nasrun Mohd Nawi[3], Andrei Victor Sandu[4]
[1]Faculty of Civil and Environmental Engineering, University Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia.
[2]Center of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis (UniMAP), 01000 Kangar, Perlis, Malaysia.
[3]School of Technology Management and Logistic, Universiti Utara Malaysia, 06010 Sintok Kedah, Malaysia.
[4]Gheorghe Asachi Technical University of Iasi, Faculty of Materials Science and Engineering, Iasi, Romania.

Abstract
Disposal of wastewater treatment plant sludge waste into landfills has become a serious threat to the global environment due to the massive generated every year. Nevertheless, a relevant alternative solution could be developed as recently rapid growing interest in the usage of sludge material to the manufacturing of fired clay brick has been observed. The utilization of these waste materials in fired clay bricks usually has positive effects on the properties such as lightweight bricks with improved shrinkage, porosity, and strength. The primary objective of this study is to focus on the properties impact of the wastewater treatment sludge incorporated into fired clay bricks. The characteristics of raw materials obtained by using the X-ray Fluorescence Spectrometer showed that the chemical composition of the raw materials of clay soil and wastewater treatment sludge was high with silicon dioxide and with the same chemical composition Type A and Type B of wastewater treatment sludge are suitable to replace clay soil as raw materials. The recommended percentage of wastewater treatment sludge incorporation was up to 20% with better physical and mechanical properties. The physical and mechanical properties were tested according to BS 3921:1985. The results showed that the utilization of Type A and Type B into brick manufacturing complied with BS 3921:1985 standard requirements. Therefore, wastewater treatment sludge can be material for brick production with appropriate mix and design and as an alternative environmentally friendly disposal method.

Keywords: *Wastewater sludge; Sewage sludge; Bricks; Compressive strength; Shrinkage; Density; Initial rate of absorption*.

INTRODUCTION

In Malaysia, about four million cubic meter of domestic sludge being produced every year. By the year 2015, Malaysia is expected to produce about 5.7 million cubic meters of domestic sludge and to be increased to about 6.6 million cubic meters by the year 2020 (Kabbashi et al., 2011). Disposal of sludge is a serious global environmental issue. In general, wastewater sludge was disposed by landfill or being burned in incinerators after pre-treatments such as dewatering, drying and firing. The disposal of this sludge will become a critical issue due to public concern and limited availability of land thus alternative disposal method is essential, as landfill is not an ideal disposal method anymore for this waste. Moreover, according to Environmental Quality (Scheduled Wastes) Regulations 2005, referring to Scheduled Waste 204 stated that sludge that contains one or several metals including Chromium, Copper, Nickel, Zinc, Lead, Cadmium, Aluminium, Tin, Vanadium and Beryllium has to be disposed as scheduled waste. Direct disposal of hazardous heavy metal sludge may cause serious effect in soil and underground water pollution.

Therefore, for the sake of assuring that the environment will not polluted by heavy metal sludge after landfill, incorporation of wastewater treatment plant sludge into fired clay brick could be one of the environmental friendly methods to dispose and reused the sludge. The main raw material for bricks is clay, clayey soils, soft slate and shale, which usually obtained from open pits with the attendance of disruption of drainage, vegetation and wildlife habitat (Hendry and Khalaf, 2001). Clay brick has been regarded as a superior building material in various applications. In view on the importance of energy saving and conservation of resources, efficient recycling of industrial waste is now a global concern. The feasibility of clay allows its combination with different types of wastes without significant modification of the production process and final product usage (Kadir and Mohajerani, 2012). Moreover, this replacement will reduce the content of clay soil in the fired clay brick that eventually reduce the manufacturing cost (Kadir et al., 2015; Kadir and Mohajerani, 2015). Nevertheless, the properties of bricks such as compressive strength, durability, leaching characteristics and indoor air quality must harmonize with the growing demands of the quality (Arsenovic et al., 2012). Utilization of sludge as an addition in construction and building material including building bricks, lightweight artificial aggregates, and cement-like materials is a win-win strategy because it will not only converts the wastes into useful materials but it also alleviates the disposal problems (Weng et al., 2003)

There were some researchers have successfully attempts the utilization of wastewater treatment sludge into fired clay bricks (Yadav et al., 2014; Garcia et al., 2012; Quesada et al., 2011; Ingunza et al., 2013; Wang et al., 2012; Liew et al., 2004). Due to the promising potential, this study was focused on investigating the optimum percentage of wastewater treatment plant sludge replacement in the manufacturing of fired clay brick due to physical and mechanical properties condition.

MATERIALS AND METHODS

Physical and Mechanical Properties

Two type of wastewater treatment plant sludge namely Type A and B was collected at wastewater treatment plant in Johor, Malaysia. The sludge was collected in a semisolid condition. Clay soil was collected at the local brick company. Both of the materials, clay soil and wastewater treatment sludge was kept properly in the box separately and been storage in the laboratory before being used. Both wastewater treatment plant sludge and clay soil were dried in the oven for 24 hours. Chemical composition and concentration has been detected by using XRF procedure. Wastewater treatment plant sludge and clay soil were crushed with suitable tools and weighed with suitable ratio. Pellet shape was made before being tested with X- ray fluorescence (XRF) machine by using model S4-Pioneer Bruker-AXS (Germany). In the brick moulding process, different percentage of wastewater treatment plant sludge were mixed with clay soil using mixer machine (1%, 5%, 10%, 15% and 20%). Water content is an important factor affecting the quality of the brick. Therefore, the compaction test was conducted to determine the optimum moisture content (OMC). By using the OMC results, the mixtures with various proportions of wastewater treatment plant sludge and clay soil were prepared to manufacture the brick. The mixtures were put into brick moulds (length 215mm, width 102, and thickness 75mm). Brick control mixtures were also made as reference. After 24hours in room temperature followed by another 24hours at 105˚C oven-dry period, the moulded mixtures were fired into a furnace at temperature of 1050˚C. As a requirement by

BS 3921:1985 standard, the brick properties including firing shrinkage, water absorption, density, compressive strength and the initial rate of absorption were determined.

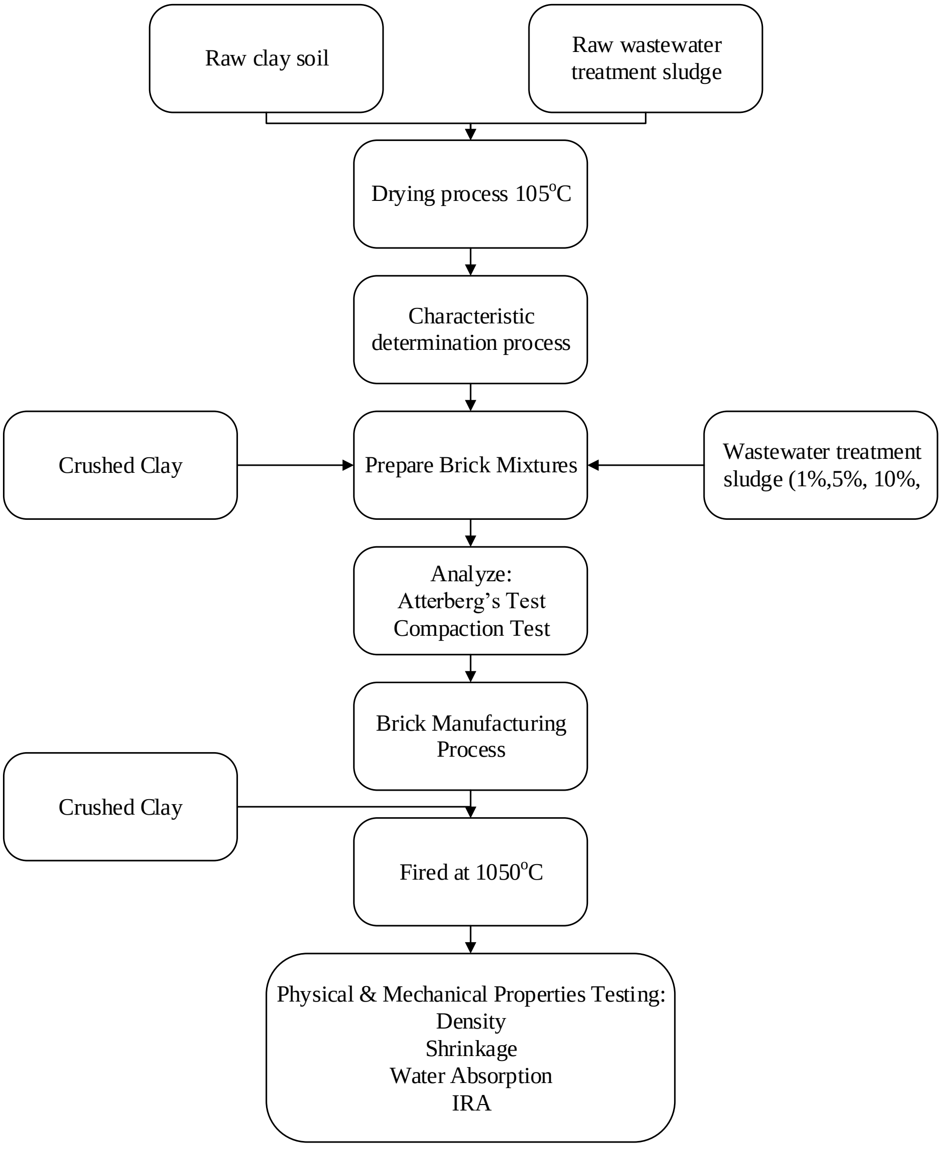

Figure 1. Flowchart for Experimental Procedure

RESULTS AND DISCUSSION

Physical and Mechanical Properties Result

X-ray Fluorescence (XRF)

Based on Table 1, it shows the element of chemical composition of raw materials for this study. The results indicated the higher percentage of chemical composition for Type A and

Type B sludge is Silicon Dioxide (SiO2) which is 14.30% and 16.30% respectively. Next, the lowest percentage of chemical composition for Type A sludge, the lowest percentage is Barium Oxide (BaO2), Strontium Oxide (SrO) and Carbon (C) which is 0.10%. For Type B sludge is Barium Oxide (BaO2) which is 0.25% and followed by Carbon (C) which 0.10% respectively. Meanwhile, for clay soil the result shows that the higher percentage is Silicon Dioxide (SiO2) which is 49.30% and followed by Aluminium Sulphide (Al2SO3) which is 18.4%. Besides that, Titanium Oxide (TiO2) shows the lowest percentage which is 0.9% then followed by Magnesium Oxide (MgO) and Carbon (C) which is 0.8% and 0.1% respectively.

Table 1. Chemical composition in raw clay soil, Type A and Type B wastewater treatment plant sludge

No	Chemical	Formula	Composition (%)		
			Type A	Type B	Clay
	Orig-g			8	
	Added-g			2	
1	Calcium oxide	CaO	6.55	2.40	ND
2	Potassium oxide	K_2O	0.71	1.07	3.09
3	Titanium dioxide	TiO_2	0.50	0.52	0.94
4	Ferric oxide	Fe_2O_3	9.85	9.35	6.78
5	Zinc Oxide	ZnO	0.39	0.37	ND
6	Carbon	C	0.10	0.10	0.10
7	Silicon dioxide	SiO_2	14.30	16.30	49.30
8	Magnesium oxide	MgO	1.15	0.85	0.80
9	Aluminum oxide	Al_2O_3	6.66	4.79	18.40
10	Chlorine	Cl	0.34	0.12	ND
11	Phosporus Pentoxide	P_2O_5	5.58	6.68	ND
12	Sodium oxide	Na_2O	0.23	ND	ND
13	Barium Oxide	BaO	0.14	0.25	ND
14	Strontium Oxide	SrO	0.12	ND	ND
15	Sulfur Trioxide	SO_3	9.20	4.61	ND

Table 2 shows the concentration of heavy metals between clay soil and both wastewater treatment sludge. The results indicates that the highest concentration of heavy metal in Type A sludge is Zinc (Zn) which is 1126 ppm followed by Barium (Br) which is 716 ppm. Next, the lowest concentration is Scandium (Sc) and Uranium (U) which is 6 and 4 ppm respectively. Other than that, the result presented that the highest concentration of heavy metal in Type B sludge is Barium (Br) with value 1223ppm followed by Zinc (Zn) which is 983 ppm. The lowest concentration is Gallium (Ga), Niobium (Nb) and Uranium (U) which is 6 ppm respectively. Next, the result obtained shows the highest concentration of clay soil is Barium (Br) which is 338 ppm and the lowest concentration is Cobalt (Co) and Uranium (U) which is 6ppm respectively.

Table 2. Heavy metals concentration in raw clay soil, Type A and Type B wastewater treatment plant sludge

No	Element	Formula	Concentration (ppm)		
			Type A	Type B	Clay
	Orig-g			9	
	Added-g			3	
1	Titanium dioxide	TiO_2	5700	5800	10200
2	Scandium	Sc	6	7	19
3	Ferric oxide	Fe_2O_3	43800	40700	60200
4	Manganese Oxide	MnO	600	500	400
5	Vanadium	V	41	44	150
6	Chromium	Cr	130	126	100
7	Cobalt	Co	8	8	6
8	Nickel	Ni	28	30	15
9	Copper	Cu	97	122	23
10	Zinc	Zn	1126	983	33
11	Gallium	Ga	8	6	17
12	Arsenic	As	12	9	8
13	Rubidium	Rb	22	29	97
14	Strontium	Sr	189	58	32
15	Yttrium	Y	18	25	37
16	Zirconium	Zr	80	80	337
17	Niobium	Nb	9	6	16
18	Molybdenum	Mo	5	8	ND
19	Tin	Sn	23	26	ND
20	Cesium	Cs	9	7	7
21	Barium	Ba	716	1223	338
22	Lanthanum	La	29	43	43
23	Cerium	Ce	90	77	95
24	Lead	Pb	55	52	30
25	Thorium	Th	26	14	23
26	Uranium	U	4	6	6

Atterberg Limit and Compaction Test

Atterberg limits and compaction test were conducted for determining the soil before proceeding with the manufacturing process of brick. Atterberg limit was carried out according to Methods of Test for Soils or Civil Engineering Purposes; Part 2: Classification Tests (BS 1377-2:1990). The properties of soil tested summarized in Table 3 below:

Table 3. Classification of soil

Soil Physical Properties	Test Results
Liquid Limit (%)	29.50
Plastic Limit (%)	21.86
Plasticity Index (%)	7.64
Degree of Plasticity	Medium Plastic
Type of Soil	Silty clay or clayey silt

Meanwhile, standard proctor test was conducted to determine the optimal moisture content (OMC) at which a given soil type will become denser and achieve its maximum dry density. The standard AASHTO compaction test was used in this study. The obtained results for Control Brick (0% sludge), Type A sludge Brick (1%, 5%, 10% and 20%) and Type B sludge Brick (1%, 5%, 10%, and 20%) were recorded and plotted. Maximum dry density was obtained from the peak point of the compaction curve (also known as optimum moisture content). OMC was summarized in Table 4. From the result show the increasing of sludge proportion increased OMC result.

Table 4. Percentage of moisture content

Mixture (%)	Moisture Content (%)	
	Type A	Type B
Control brick	17.0	17.0
1% brick	17.8	17.4
5% brick	18.2	18.1
10% brick	20.4	20.3
20% brick	21.9	21.0

Mechanical properties

Density

Generally, value of bulk density for bricks that was made with clay is 1500 kg/m3 to 2000kg/m3. The result of fired clay brick with different percentage of wastewater treatment sludge was illustrated in Figure 2 and tabulated in Table 5. As shown, the pattern of the graph was illustrated decreasing due to the increasing percentage of wastewater treatment sludge. This is related with the result of water absorption. The finding of Benlalla et al., (2015) stated bricks that absorb more water will exhibits a large pore size and the density of bricks will becomes smaller. From the result for Type A and Type B sludge show that Wastewater treatment plant sludge Brick (20%) obtained the lowest density at 1226.55kg/m3 and 1247.24kg/m3 respectively compare to Wastewater treatment plant sludge Brick (1%) at

1530.46kg/m3 and 1562.52kg/m3. From this study, lightweight of brick were produced. However, the control brick obtained the highest value of density but still complying with the standard. Nevertheless, lightweight brick provide advantages in terms of transportation cost because it is lighter than normal brick (Kadir et al., 2011).

Table 5. Density of the manufactured bricks

Mixture Identification (%)	Density (kg/m^3)	
	Type A	Type B
Control	1610.64	1610.64
1	1562.52	1530.46
5	1544.56	1448.86
10	1436.45	1414.75
20	1247.24	1226.55

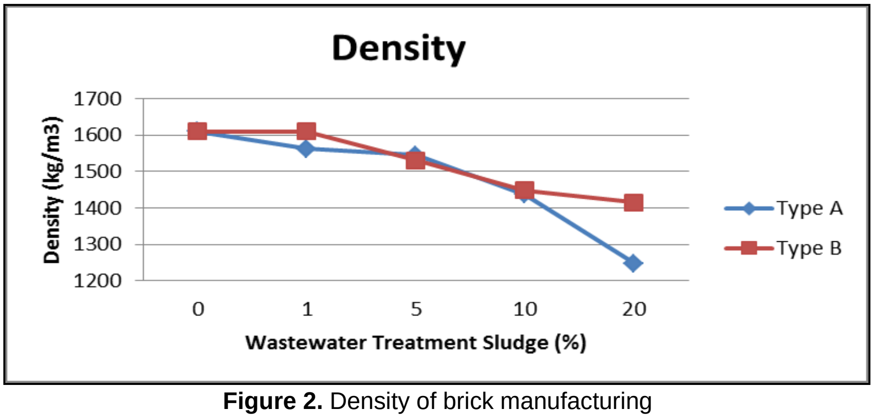

Figure 2. Density of brick manufacturing

Shrinkage

In this part, shrinkage of brick was determined after firing with temperature up to 1050oC. Firing shrinkage was defined as the contracting of mixture hardened due to the loss of capillary water (Koratich, 2009). Shrinkage was measured by determining the length before and after firing occurred. The good quality of bricks exhibits shrinkage is below 8%. From this study shows that increasing sludge proportions will increase the shrinkage of bricks. Based on Table 6, shrinkage of control brick is lower than the brick with additional sludge with 1.63%. Additional sludge 1% of the sludge of Type A and Type B, the percentage of shrinkage increase with value 3.57% and 3.07% respectively. Meanwhile, for 20% percentage of sludge, the shrinkage is increasing up to 6.61% and 6.18%. Nevertheless, all manufactured bricks do not exceed 8% of shrinkage. Based on Weng et al., (2003), normally, a quality of brick can be further assured according to the degree of firing shrinkage. The result of shrinkage of bricks was summarized in Table 6 and demonstrated on Figure 3 below.

Table 6. Shrinkage of Fired Clay Brick

Mixture Identification (%)	Shrinkage (%)	
	Type A	Type B
Control	1.63	1.63
1	3.57	3.07
5	4.88	4.86
10	5.76	5.76
20	6.61	6.18

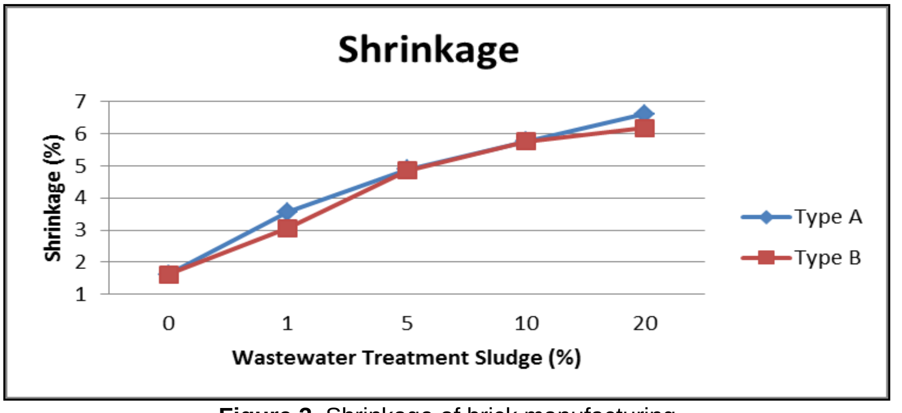

Figure 3. Shrinkage of brick manufacturing

Water Absorption

Amount of water that a brick can absorb was measured by using water absorption test. Water absorption test was conducted after firing process and it is a key factor of bricks durability. The less water infiltrates into brick, the more durability of the brick and resistance to the natural environment are expected. Weight of the brick before and after firing was measured in order to get the percentage of water absorption value. Based on Table 7, it shows that the percentage water absorption of control brick is lower compared to brick with additional sludge with 8.22%. According to John et al., (2001), the percentage of water absorption is increased almost linearly with the increase in wastewater treatment sludge content. The same trend was demonstrated in this study, with up to 20% of sludge, it shows the increasing amount of water absorption which 21.19% is for Type A wastewater treatment plant sludge and 19.69% for Type B wastewater treatment plant sludge.

Table 7. Water Absorption of Fired Clay Brick

Mixture Identification (%)	Water Absorption (%)	
	Type A	Type B
Control	8.22	8.22
1	14.95	8.71
5	15.35	16.97
10	15.68	18.83
20	21.19	19.69

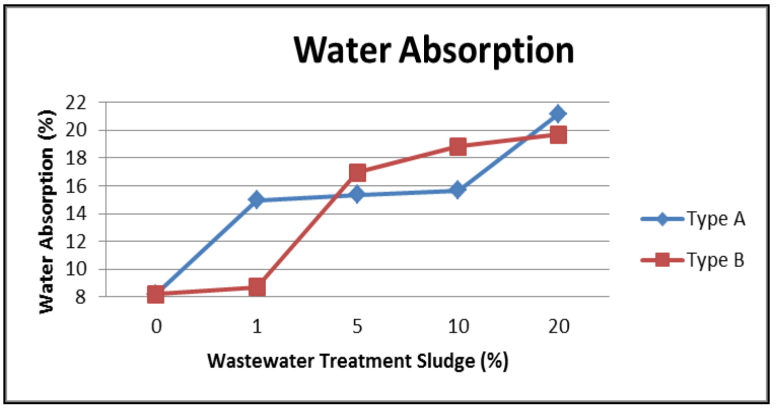

Figure 4. Water Absorption of brick manufacturing

Initial Rate of Absorption (IRA)

The initial rate of absorption (IRA) was measured in kg/m2.min and Table 8 and Figure 5 showed the result of IRA from two types of sludge's that have been incorporated into fired clay brick. Based on the results, it was recorded that the control brick has the lowest value of IRA compare to other percentages of sludge. For Type A sludge, it also shown that the increasing value is due to the increasing percentage of sludge. For 1% and 5% of sludge, it indicates that the value of IRA is 5.15 kg/m2.min and 6.21 kg/m2.min respectively. As for Type B sludge, it shows that increasing value of IRA which is 5.53 kg/m2.min. Next, for 5% and 10% of Type B sludge with value 9.33 kg/m2.min and 9.76 kg/m2.min respectively. At 20% of sludge, Type B sludge indicates IRA value is 12.60 kg/m2.min higher that Type A sludge which is 10.98 kg/m2.min. Based on IRA result, it can be concluded that the increasing percentage of sludge will increase the value of IRA. An unacceptable high value of IRA can lead to volume changes that would result in cracking of the brick structural (Kadir et al, 2009).

Table 8. Initial Rate of Absorption of Fired Clay Brick

Mixture Identification (%)	Initial Rate of Absorption (IRA) (kg/m^2.min)	
	Type A	Type B
Control	4.36	4.36
1	5.15	5.53
5	6.21	9.33
10	7.14	9.76
20	10.98	12.60

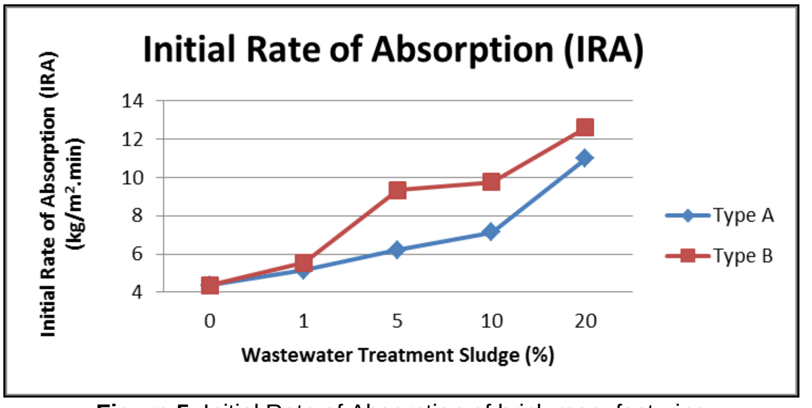

Figure 5. Initial Rate of Absorption of brick manufacturing

Compressive Strength

The compressive strength is the most important test for assuring the engineering quality of building material (Lin and Weng, 2001). In this study, strength of brick was determined by using Universal Testing Machine (UTM) for every percentage of sludge that has been incorporated into fired clay brick. Table 9 and Figure 6 shows the value of compressive strength at different percentage of brick. The result is indicates the strength of brick with different percentage of sludge after firing process. The highest value of compressive strength was control brick with 27.1MPa. In this study, the value of compressive strength highly related with the amount of sludge. The increase of sludge proportion will decreased the compressive strength of bricks. As for maximum value of sludge proportion which is 20% for both sludge, it shows the lowest value of compressive strength which is 2.6MPa for Type A and 2.1Mpa for Type B. Increasing percentage of sludge has decreased the strength of the brick but the strength of brick is still complying with minimum standard of compressive strength which is less than 5MPa except for 20% of sludge utilized.

Table 9. Compressive Strength of Fired Clay Brick

Mixture Identification (%)	Compressive Strength (MPa)	
	Type A	Type B
Control	27.1	27.1
1	23.0	22.3
5	15.0	11.3
10	9.3	6.8
20	2.6	2.1

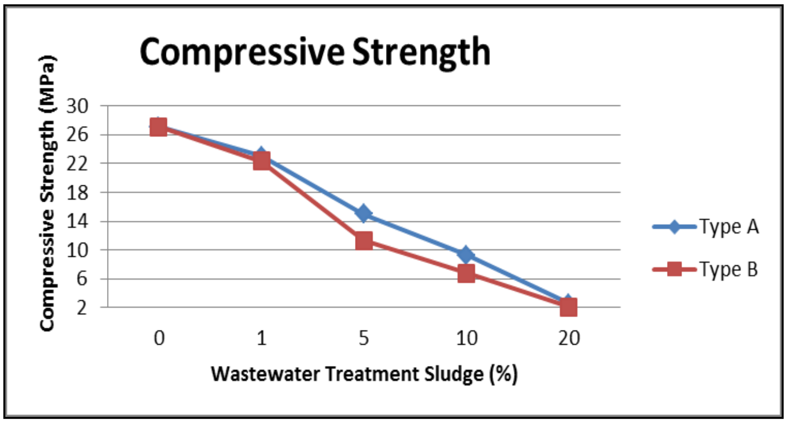

Figure 6. Compressive Strength of brick manufacturing

CONCLUSION

As a conclusion, all the characteristic, percentages of sludge, physical and mechanical properties incorporated with wastewater treatment sludge waste (Type A and Type B) were determined. The characteristic that was found by XRF shows the chemical composition of the raw material of clay soil and wastewater treatment sludge was high with silicon dioxide (SiO2). Therefore, the same characteristic of wastewater treatment sludge is adequate to replace clay soil as a raw material. From the result obtained shows density value for control is 1610.64 kg/m3 and with additional 20% of Type A sludge incorporated into fired clay brick, the value decreased to 1247.24 kg/m3. As for Type B sludge, the value of density decreased to 1226.55 kg/m3 with 20% of sludge. The shrinkage value of Type A sludge brick was increased from 1.63% (control brick) to 3.57% (for 1% of sludge), 4.88% (for 5% of sludge), 5.76 (for 10% of sludge) and 6.61% (20% sludge) of wastewater treatment sludge content respectively. Next, for Type B sludge, shrinkage value also shows the same pattern with Type A sludge. It increased from 1.63 % for control brick to 3.07%, 4.86%, 5.76% and 6.18% for 1%, 5%, 10%, and 20% of wastewater treatment sludge content respectively. The density and shrinkage for all brick were satisfied with average mass (1500kg/m3) and complied with the standard and shrinkage which is below 8%. In addition, water absorption values of Type A and Type B were increased in the range 14.95% to 21.19% and 8.71% to 19.69%. The initial rate of absorption (IRA) results is 4.36 kg/m2/min for control brick and increased to 12.60 kg/m2.min for 20% of Type B sludge brick and 10.98 kg/m2.min for Type A sludge brick respectively. The compressive strength of brick was reduced from 27.1MPa (control brick) to 2.6MPa for Type A sludge brick and 2.1 MPa for 20% of Type B sludge brick respectively. As a conclusion, the result found that the brick with 5% Type A sludge produce a good condition of brick due to its physical and mechanical properties that have been tested and complied with the standard. The different percentage has shown the different result obtained. It could happen due to a relation between the suitable proportions of soil and wastewater sludge that has been incorporated. The mixture of clay soil and wastewater treatment sludge can be mix properly and balance accordingly to suitability on the bond. Nevertheless, all the wastewater treatment sludge brick comply with the British Standard. It can be concluded that wastewater treatment is suitable as one of an alternative to replace clay soil in brick manufacturing while providing an appropriate waste disposal method.

ACKNOWLEDGEMENTS

The authors express their gratitude to the University Tun Hussein Onn Malaysia, for the facilities of this research.

REFERENCES

Arsenovic, M., Radojevic, Z., & Stankovic, S. (2012). Removal of toxic metals from industrial sludge by fixing in brick structure. *Construction and Building Materials*, *37*, 7-14.

Benlalla, A., Elmoussaouiti, M., Dahhou, M., & Assafi, M. (2015). Utilization of water treatment plant sludge in structural ceramics bricks. *Applied Clay Science*, *118*, 171-177.

Koratich, D. (2015). Dry shrinkage; Retrieved from http://www.engr.psu.edu/ce/courses/ce584/concrete/library/cracking/dryshrinkage/dryingshrinkage.html

Durante Ingunza, M. P., Duarte, A. C., & Nascimento, R. M. (2010). Use of sewage sludge as raw material in the manufacture of soft-mud bricks. *Journal of Materials in Civil Engineering*, *23*(6), 852-856.

Eliche-Quesada, D., Martínez-García, C., Martínez-Cartas, M. L., Cotes-Palomino, M. T., Pérez-Villarejo, L., Cruz-Pérez, N., & Corpas-Iglesias, F. A. (2011). The use of different forms of waste in the manufacture of ceramic bricks. *Applied Clay Science*, *52*(3), 270-276.

Hendry, A. W., & Khalaf, F. M. (2010). *Masonry wall construction*. CRC Press.

John, V. M., & Zordan, S. E. (2001). Research & development methodology for recycling residues as building materials—a proposal. *Waste Management*, *21*(3), 213-219.

Kabbashi, N. A., Alam, M. Z., & Rahim, K. B. A. (2010). Dynamic Modelling of Bioconversion of Domestic Wastewater Sludge for Cellulase Enzyme. In *Survival and Sustainability* (pp. 1193-1202). Springer Berlin Heidelberg.

Kadir, A. A., & Mohajerani, A. (2011). Recycling cigarette butts in lightweight fired clay bricks. *Proceedings of the Institution of Civil Engineers-Construction Materials*, *164*(5), 219-229.

Kadir, A. A., & Mohajerani, A. (2015). Effect of heating rate on gas emissions and properties of fired clay bricks and fired clay bricks incorporated with cigarette butts. *Applied Clay Science*, *104*, 269-276.

Kadir, A. A., Sarani, N. A., & Leman, A. M. (2015). Testing on building material using waste material in fired clay brick. In *Materials Science Forum* (Vol. 803, pp. 330-336). Trans Tech Publications.

Liew, A. G., Idris, A., Wong, C. H., Samad, A. A., Noor, M. J. M., & Baki, A. M. (2004). Incorporation of sewage sludge in clay brick and its characterization. *Waste Management & Research*, *22*(4), 226-233.

Lin, D. F., & Weng, C. H. (2001). Use of sewage sludge ash as brick material. *Journal of Environmental Engineering*, *127*(10), 922-927.

Mohajerani, A. (2012). Properties improvement of fired clay bricks incorporating with cigarette butts. In *Advanced Materials Research* (Vol. 535, pp. 1723-1730). Trans Tech Publications.

Wang, H. B., Lin, Z. Z., & He, Z. Y. (2012). A New Brick Prepared from Municipal Sewage Sludge and Shale. In *Advanced Materials Research* (Vol. 374, pp. 18-23). Trans Tech Publications.

Weng, C. H., Lin, D. F., & Chiang, P. C. (2003). Utilization of sludge as brick materials. *Advances in environmental research*, *7*(3), 679-685.

Yadav, S., Agnihotri, S., Gupta, S., & Tripathi, R. K. (2014). Incorporation of STP Sludge and Fly ash in Brick Manufacturing: An attempt to save the Environment. *Int. J. Adv. Res. Technol*, *3*(5), 13.